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INTERPRETATION OF X-RAY LINE SPECTRA FROM EXPLODED-WIRE ARRAYS.(U)
MAR 78 P BURKHALTER, J DAVIS, J RAUCH

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Interpretation of X-Ray Line Spectra from Exploded-Wire Arrays

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Temperatures and densities were determined from the plasma implosion formed at the center of symmetrical exploded-wire arrays. Temperatures of 500-850 eV were found from line ratios in Al and Si shots using various plasma models. The recombination temperatures for these elements were 400-500 eV. Higher implosion temperatures of 1.5 to 2 keV were found in Ti and Fe shots and of 2.5 to 4 keV for Mo wire shots. The densities were $\sim 1 \times 10^{20}$ el/cm^3 for the spatially-integrated implosion region. Intense emitting regions of $\sim 500\ \mu m$ in size were observed in densitometer contours of Al plasma pinhole images.

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18. Supplementary Notes (Continued)

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INTERPRETATION OF X–RAY LINE SPECTRA FROM EXPLODED–WIRE ARRAYS

I. INTRODUCTION

X-ray spectra in the 1-7 keV region have been recorded with convex, curved-crystal spectrographs in the PITHON and BLACKJACK 4 high voltage exploded-wire generators. The spectra were recorded from the plasma implosion formed at the center of the symmetrical imploded-wire arrays. The x-ray data, collected throughout the periodic table (Mg thru W) on No-Screen X-ray film, were processed to obtain relative spectral intensities. Temperatures and densities were estimated for the entire implosion region from line ratio techniques and the slopes of the continuum in exploded-Al-wire spectra. The plasma models used were the coronal model with dielectronic recombination, average atom model calculations, and a collisionally-dominated, radiation transport code having a cylindrical temperature input profile together with published plasma x-ray line ratio data.

II. EXPERIMENTAL

Symmetrical-six-wire arrays were exploded in the PITHON at Physics International Company (P.I.) (1) and the BLACKJACK 4 generator at Maxwell Laboratories, Inc. X-ray spectra were collected, processed, and interpreted from Al, glass, Ti, stainless steel, Mo,and W wires. The x-ray film data selected were representative of spectral data from shots forming good plasma implosions as evidenced from intense

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x-ray signals using active detectors. Pinhole images through a 100 μm and 50 μm apertures were available from two Al shots taken at Physics International.

Convex, curved crystal geometries were used on both generators, mostly with two crystals recording simultaneous data onto No-Screen x-ray film. At P.I. the crystals used were KAP (15.9 mm-radius, 2d = 26.6 Å) graphite, (2d = 6.7 Å) and LiF (126-mm radius) (2d = 4.03 Å) and at Maxwell KAP (31.8-mm radius) and LiF (6.3 mm radius) spectrographs collected the x-ray spectra. Thin absorption filters of Kimfoil and Kapton were used to record Al data and thicker mylar step filters allowed data collection at various exposure levels on the same film. Valuable high-dispersion Al spectra were recorded on a few of the shots from both generators. The spectra were scanned at the Naval Research Laboratory (N.R.L.) with a digitizing Grant scanning densitometer. Film densities were recorded every 10 μm across the films using a 20 μm wide densitometer slit width. This was adequate for profile resolution as the x-ray line widths varied mostly in the range of 100-300 μm. The film densities were converted to spectral intensities using No-Screen sensitometric data of Dozier, et al. (2), x-ray absorption coefficients published by Henke (3) for the filters, and unpublished, curved-crystal response data calculated by Brown (4). In this report the spectral data are reported as relative

intensities of the x-ray emission incident on the x-ray crystals. X-ray line ratios were obtained from the spectral peaks.

Temperature predictions were made in this work from various plasma models. The recombining temperatures were determined from the dielectronic satellites-to-resonance line ratios in Al and Si based on line ratios published by Bhalla and Gabriel (5) and were estimated from the slopes of the free-bound H-like continuum in the Al spectra. Temperatures for the hot plasma emission were obtained from line ratios using coronal model calculations that include dielectronic recombination and a 1D multi-cell radiation model that incorporates a ray trace method to handle the radiation transport. The model assumes that the input energy from the generator dumps into a finite diameter (0.1 cm) implosion plasma formed at the center of the array with a constant ion density of 1×10^{19} ions/cm^3. A complete development and discussion of the multi-cell radiation transport model will be treated in a correlated report by Davis, et al. (6).

Density predictions were made from the ratio of the resonance-to-intercombination lines ($1s^2$-$1s2p\ ^1P/1s^2$-$1s2p\ ^3P$) in Al and Si using published calculations by Vinogradov, et al. (7) for laser-produced plasma densities. The merging of the high Rydberg transitions in Al and Ti allowed for

density estimates. A density was determined for the Mo spectrum based on the average atom model calculations of Rozsnyai (8).

III. RESULTS

A. Al wire arrays

An Al spectrum from shot BL1 was collected on BLACKJACK 4 through 1/2-mil mylar step filters. Digitized spectral scans were made of five spectra and the spectral intensity trace for data collected through 1 1/2-mils of mylar is shown in fig. 1. Al is readily stripped to the K-shell in exploded-wire plasmas. For this shot, the H-like resonance line (1s-2p) was about 60% the intensity of the He-like resonance line ($1s^2$-$1s2p\ ^1P$). These two lines are optically thick in a uniform hot, dense plasma of 10^{20} el/cm^3. The resonance lines require large correction for the absorption by the mylar filter. For these reasons, temperatures were determined also from the ratio of the H-like 1s-3p line and the He-like $1s^2$-1s5p line. These lines are seen to be close in wavelength (near 6 Å) and are generally closer in exposure levels than are the resonance lines to the 2p level. Therefore uncertainties in data processing would be minimized (less than 5 percent) for the ratio of 1s-3p to $1s^2$-1s5p lines. The 1s-3p line can be optically thin in Al.

An agreement in temperature estimated from the two sets of line ratios provides reassurance of the consistency of the data processing and model predictions. A uniformly decreasing free-to-bound H-like continuum is seen between 6 and 4 Å in the spectrum. A plasma temperature of 550 eV is obtained for this spectrum. Line ratios and temperature estimates from various models are listed in Table I. The density value of 1×10^{20} el/cm^3 was obtained from the ratio of the He-like resonance-to-intercombination line. The higher Rydberg transitions in H-like 1s-4p to the 1s-9p lines was observed in the high dispersion spectrum for shot BL1.

The spectral intensities for the Al shot PI1 from PITHON is shown in fig. 2 both in first and high dispersion. The entire H- and He-like spectra were recorded in the first order spectrum. The density from the $^1P/^3P$ ratio was 7×10^{19} el/cm^3. The higher Rydberg transitions were obtained with high dispersion from the (013) plane in KAP. The resolution achieved is comparable to that obtainable with a PET crystal (2d = 8.726 Å). In both the He-like and H-like series transitions to the 9p level are the last distinct high Rydberg transition. A density estimate of 3×10^{20} el/cm^3 is obtained from the series merging technique (9). The H-like 1s-3p and He-like 1s^2-1s5p lines were distinct in the high dispersion spectrum and a temperature value of 750 eV was obtained as a thin temperature estimate. This value is the same as was obtained from the 1s-3p/1s^2-1s5p ratio in the Maxwell shot. A sequence of Al shots

were taken on PITHON on six wire arrays with increasing input power. The spectral results are seen in fig. 3. The first order spectrum for shot PI2 recorded the entire spectral lines. The density was determined to be 1 x 10^{20} el/cm^3 from the $^1P/^3P$ ratio. This shot formed a cooler implosion than shot PI1. In shot PI3 the He-like $1s^2$-1s2p resonance lines were not recorded and in shot PI4 both the H-like and He-like resonance lines were missing. This cut off of the longer wavelength lines can be caused by a slight rotation of the spectrograph relative to the sources. In this series of shots the missing second-order spectra is caused by a spectrograph rotation. A somewhat larger entrance aperture for the KAP spectrograph would be beneficial in lessening the chances of spectral cutoff. The higher Rydberg transitions were fully recorded in these spectra and the ratio of the 1s-3p/$1s^2$-1s5p lines gave an indicated doubling of plasma temperature in the series. As the plasma temperature increased the magnitude of the H-like free-bound continuum is seen to be enhanced relative to the spectral lines. Also one can infer from the shape of the free-bound continuum in shot PI4 that the peak energy of the free electrons has increased.

A shot PI5 from a 12-wire array produced an Al spectrum similar to shot PI3. The slight differences in spectral line ratios and continuum slopes for shots PI5 and PI3 are reflected in the temperature estimates in Table I. Pinhole images of the

plasma implosion were recorded through a 100 μm aperture on Kodak type AA film on shot PI5. The first film recorded the x-ray emission mainly above 1 keV. An over exposed film resulted on the first film; however, a second film recorded a readable image with the first film serving as a transmission filter. The pinhole image for x-ray continuum radiation above 3 keV was recorded in the pinhole image shown in the upper portion of fig. 4. Two-dimension density contours of the pinhole image at two magnifications are shown. The contour step was set at 0.2 density units. Most striking are the intense regions of x-ray emission along the implosion. All the spectra in this report were collected without spatial resolution. It is probable that in the case of Al the recorded spectra were emitted from a few localized regions of about 500 μm in size, with cores of $\leq$ 100 μm. Unfortunately pinhole images were not available for the other Al spectra shown in this report except for shot PI2 shown in fig. 5. The emission from this image also appears to be localized into small spots. Some of the more intense regions appeared split into several spots instead of localized spherical shapes seen in shot PI5.

B. Glass wire array

A six-wire array of glass fibers was exploded in PITHON yielding an x-ray spectrum of Si shown in fig. 6. Superimposed on the spectrum were Al lines. The origin of the Al ions is presumed to arise from the Al anode. The cathode housing

was brass in this experiment and aluminum is not commonly found in glass at the percent level. The temperature determined from the ratio of the Si XIV (1s-2p)/Si XIII($1s^2$-1s2p) lines is 650 eV based on the coronal model. The temperature from the same line ratio for the Al lines in this plasma yield the same 650 eV (thin) temperature based on the transport model calculations for an electron density of $\sim 10^{20}$ cm^{-3}. This is the density determined from the $^1P/^3P$ ratio in Si XIII. The free-bound continuum was too low for a recombination temperature determination in the Si spectrum. The glass shot PI6 was fired at about the same mass loading and input power as the Al shot PI1 which yielded a higher Al plasma temperature.

A second-order Si spectrum was recorded with the KAP crystal on this glass shot PI6. The well-dispersed Si XIII resonance lines are shown in fig. 7. The $^1P/^3P$ ratio in He-like Si XIII gave the same 1×10^{20} el/cm^3 density estimate as was determined from the first-order spectrum. Analysis of the line intensities for the dielectronic recombination lines j and k gave a cool recombining plasma temperature estimate of 4.5×10^6 K or about 400 eV.

C. Ti wire arrays

The Ti spectra collected with LiF crystals for BLACKJACK 4 (shot BL2) and PITHON (shot PI7) are shown together in fig. 8. The He-like lines are the most dominant in each spectrum. The experimental intensity ratio for the H-like (1s-2p)/ He-like

($1s^2$-$1s2p\,^1P$) lines is ∿ 3.5% in each spectrum. The temperature estimatesfor the Ti spectra are 2.0 keV with a coronal model that includes dielectronic recombination and 2.1 keV for the multi-cell transport model. For an assumed plasma ion density of 10^{19} cm^{-3}, the 4.7 keV radiation for the Ti lines is optically thin so that the temperature determinations are not opacity affected. The density of the exploded-Ti-wire plasmas could not be determined from the ratio of He-like $^1P/^3P$ because this ratio is density sensitive only above 10^{22} el/cm^{-3}. However a density estimate of 6 x 10^{20} el/cm^{-3} was obtained from the series limit from the observation of the $1s^2$-$1s7p$ line being the last distinct line before series merging in shot BL2. The differences in the spectra in regard to plasma temperatures was the evidence of Ne-like lines seen in the PITHON shot indicating cool plasma formation (temperature < 150 eV) that was not seen in the BLACKJACK 4 shot BL2.

D. Stainless steel array

The spectrum collected with the LiF crystal for shot BL3 from BLACKJACK 4 is shown in fig. 9. The most abundant ionization stage is Li-like in both the Cr and Fe spectrum. The H-like Fe XXVI line is just visible at ∿ 1.8 Å. The Fe radiation is optically thin in exploded-wire plasmas. A coronal temperature estimate of 1.5 keV is obtained for the Fe spectrum. There is also evidence (Fe XIV-XVII lines) for cool plasma formation with a coronal temperature of 150 eV.

The long wavelength stainless steel spectrum collected with the KAP crystal is shown in fig. 10. The most distinct Fe lines belong to Li-like Fe XXIV and are identified in the figure together with lines from Li-like Cr XXII. An Al spectrum was recorded in this shot. Al ions could be introduced into the plasma from either the anode or cathode in the BLACKJACK 4 generator. The plasma temperature determined from the Al line ratio for the $1s\text{-}2p/1s^2\text{-}1s2p$ was 0.80 keV.

E. Mo wire array

The first-order KAP spectrum of an exploded-Mo-wire array shot PI8 in PITHON is shown in fig. 11. The most intense and distinct lines in the spectrum arise from Ne-like Mo XXXIII. The position of the lines in Mo XXXIII and in F-like Mo XXXIV are indicated below the spectrum. The height of the line positions indicate the theoretical oscillator strengths. A detailed spectroscopic analysis of the complex exploded-Mo-wire spectra from both single and multi-wires has been recently completed (10). The region of the spectrum between 5.0 and 5.5 Å contain Na-like 2p-3s satellite lines as shown in fig. 12. An analysis of the satellite-to-resonance line ratio predicts a temperature range of 2.5-3 keV, based on coronal calculations at low plasma densities (11). The ratio of the F-like to Ne-like spectral patterns indicate a coronal temperature of about 4 keV for the exploded-Mo-spectrum. Transitions to high Rydberg levels in Mo were examined in the spectrum recorded with a

graphite crystal. Distinct lines to the 7p level were observed in Mo XXXIII. An electron density estimate of 10^{20} el/cm^3 was obtained using line broadening theory incorporated in the average atom model (12).

F. W wire arrays

W spectra were not obtained with the KAP spectrographs from either generator and therefore a temperature for the W thermal plasma could not be determined. The W thermal spectrum for single wires exploded in Gamble II were stripped into the M shell and intense 3d-4f lines in W^{+46} were observed (13). W spectra collected with LiF crystals in both generators were similar to that reported for single-W-wires (13). The spectra were the inner L-shell spectra of W produced by energetic electrons.

IV. SUMMARY AND DISCUSSION

The plasma temperatures and density determined from the interpretation of the exploded-wire arrays are summarized in Table II for wires Al through Mo. The most abundant ionization stage changes systematically from either He or H in Al to Ne-like in Mo. The temperatures for the higher power shots were roughly 0.5-0.85 keV for Al, 1.5-2 keV for Ti, Cr, Fe and 2.5-4 keV for Mo. Hotter plasma temperatures are therefore associated with the implosions from higher Z elements. It is not clear why the temperature determined from the Al and Fe

spectral lines are different for ions in the same implosion (SS shot BL3); however, the origin of the ions in the plasma were different. In addition to the hot plasma temperatures, evidence of cooler plasma ∿ 150 eV was found in several spectra.

Much of the effort both experimentally and theoretically involved Al wire spectra in this work. The experimental line ratios for the two sets of H-like/He-like lines for Al spectra from the various P.I. and Maxwell Laboratory shots together with temperatures are given in Table I. The uncertainties in spectral line intensities and line ratios are estimated to be ± 20%. This is the level of agreement for the $1s\text{-}3p/1s^2\text{-}1s5p$ lines between the first and high dispersion spectrum in PITHON. shot PI1 and for this line ratio in Al spectra collected through different mylar step filters for the BLACKJACK 4 shot BL1. Factors contributing to uncertainties in spectral line intensities include variations in the diffraction responses for the curved KAP crystals and exposure irregularities due to grain size structure using No-Screen x-ray film. Differences in obtaining line ratios from peak heights or from integrating line intensities were less than 10% for the KAP data. This agreement results because the line profiles are constant in the low dispersion found in the KAP spectral data for Al. Temperatures can be compared between those determined from the two sets of line ratios. For the PITHON shot PI1 and the BLACKJACK 4 shot BL1 the agreement between sets is within 15% for the thick and thin

calculations, but agreement was not found for the PITHON shot PI2. For the three shots in which the 1s-2p/$1s^2$-1s2p ratios were available, the coronal temperature estimate is about midway between the thick and thin temperatures. If the x-ray spectral emission recorded for Al plasmas arises from a uniform plasma volume at 10^{20} el/cm^3 for a 0.1 cm diameter, then the actual Al plasma would have a temperature corresponding to the thick case. If the emission in the Al plasma is recorded predominately from intense emitting regions only 500 μm in size as suggested by the pinhole image contours, then the temperatures estimated for thin plasma would be appropriate. For a better understanding of the origin of the Al spectral emission in plasma implosions require spatial spectral data correlated with pinhole images. The temperatures obtained from the slopes of free-bound hydrogenic continuum are close to the values the transport model predicts for thick plasma cases. The two methods used for density determinations in Al plasmas have yielded results between 7×10^{19} to 3×10^{20} el/cm^3 for some average value of density corresponding to intense emitting regions of the plasma implosion. An electron density of $\sim 1 \times 10^{20}$ el/cm^3 is consistent with densities found in the higher Z-wire implosions and is lower than the 10^{21} el/cm^3 densities for single exploded-Al-wire plasmas determined by the same spectral techniques. If the density for the Al implosion were an order of magnitude higher at 10^{21} el/cm^3, the temperature determination

from the ratio of the 1s-2p resonance lines would be lowered to 475 eV and the plasma would be thick even for 500 μm spots. The $1s^2$-1s5p line is affected by opacity to a greater degree than the 1s-3p line and the temperatures determined by the two sets of line ratios would have a greater disagreement than found in Table I. The temperature determined by the line ratio 1s-3p/$1s^2$-1s5p would become 350 eV at densities of 10^{21} el/cm^3. The consistency of the plasma temperature and density determinations from within each spectrum and between elements (sometimes within the same shot but from different spectral planes) appears at an adequate confidence level for the spatially and temporally integrated data in this study. The plasma temperatures determined from the Al spectra indicate that increased input power produces increased plasma heating (PITHON shots PI2-PI4). At constant input power levels, higher Al-plasma temperatures have resulted from lower wire mass loading. For two shots PI5 and PI3, very similar Al spectra resulted when six and twelve wire arrays were fired while maintaining constant input power and mass loading. Also large shot-to-shot variations have not been observed in Al implosion spectra. Recent Al wire array data collected on BLACKJACK 4 have shown the expected 1s-2p resonance lines, thus substantiating their absence in the high input power shots from PITHON as being an experimental cutoff.

The results and questions that arise in the interpretation of the spectral data indicate need for upgrading the collection of the x-ray data. The greatest uncertainty regarding the plasma temperature and density estimates and the adequacy of the plasma transport model is the spatial origin for the recorded spectral data. The most important next step is to collect spectra with spatial resolution together with simultaneous pinhole data through differential filters. The need for use of higher dispersive x-ray crystals such as PET or quartz is apparent from the well-resolved lines that were occasionally collected in higher order KAP data. Higher dispersion combined with spatial resolution will provide better diagnostics and better pictures of the plasma formation to improve the theoretical modeling and thereby refine the temperature estimates. The use of high-dispersive crystals also allows sufficient spatial separation of the He- and H-like resonance lines in Al and Ti that PIN or XRD active detectors instead of film can be placed behind the diffracting crystals to obtain temporal information concerning the formation of these ions in the plasma implosion.

Acknowledgment:

The authors wish to thank D. Brown at N.R.L. for suggesting the possibility of diffraction from the (013) plane in KAP crystals.

References

1. C. Stallings, K. Nielsen and R. Schneider, Appl. Phys. Lettr. 29, 404 (1976).

2. C. M. Dozier, D. B. Brown, L. S. Birks, P. B. Lyons and R. F. Benjamin, J. Appl. Phys. 47, 3732 (1976).

3. Burton L. Henke and Eric S. Ebisu, Adv. X-Ray Analysis 13, 639 (1969).

4. D. B. Brown (to be published).

5. C. P. Bhalla, A. H. Gabriel and L. P. Presnyakov, Mon. Not. R. Astr. Soc. 172, 359 (1975).

6. J. Davis (to be published).

7. A. V. Vinogradov, I. Yu. Skobelev and E. A. Yukov, Sov. J. Quant. Electron. 5, 630 (1975).

8. B. F. Rozsnyai, private communication.

9. J. Davis, "Series Merging Technique," N.R.L. Memorandum Report 2655, Oct. 1973.

10. P. G. Burkhalter, R. Schneider, C. M. Dozier and Robert D. Cowan, "Spectra of Mo XXXI-XXXIV from Exploded Mo-Wire Plasmas," (to be published) Preprint 108.

11. L. J. Roszman, "Dielectronic Recombination Rates for Heavy Ne-like Ions in Tokamak Type Plasmas," Bull. Am. Phys. Soc. 21, 1118 (1976), to be published.

12. B. F. Rozsnyai, J. Quant. Spectrosc. Radiat. Transfer <u>17</u>, 77 (1977).

13. P. G. Burkhalter, C. M. Dozier and D. J. Nagel, Phys. Rev. <u>A15</u>, 700 (1977).

Table I — Temperatures for exploded-Al-wire spectra

generator	shot	Expt. ratio	Temperatures		Expt. ratio	Temperatures			
		$1s\text{-}3p/1s^2\text{-}1s5p$	transport model		$1s\text{-}2p/1s^2\text{-}1s2p$	transport model		coronal	continuum
			thick	thin		thick	thin		
PITHON	PI1	2.4-2.9	525	750	0.60	575	850	700	500
	PI2	0.8	400	500	0.57	550	825	700	475
	PI5	2.2	500	700	N.A.*				500
	PI3	2.6	525	750	N.A.				525
	PI4	4.5	650	900	N.A.				N.D.
BLACKJACK	BL1	2.3-2.6	550	750	0.56	550	825	700	550

*N.A. (not available)

N.D. (not determinable)

Table II — Summary of Exploded-Wire Results

WIRES	MOST ABUNDANT IONIZATION STAGE	TEMP. T_e	MODEL	DENSITY N_e
Al	He or H	500-750	transport	1×10^{20}
		700	coronal	
		500	f-b continuum	
SiO_2	He	650	coronal	1×10^{20}
		400	recombining plasma	
Ti	Li or He	2.1	transport	6×10^{20}
		2.0	coronal	
Cr,Fe	Li	1.5	satellite lines	
Mo	Ne or F	2.5-4	coronal	$\sim 1 \times 10^{20}$

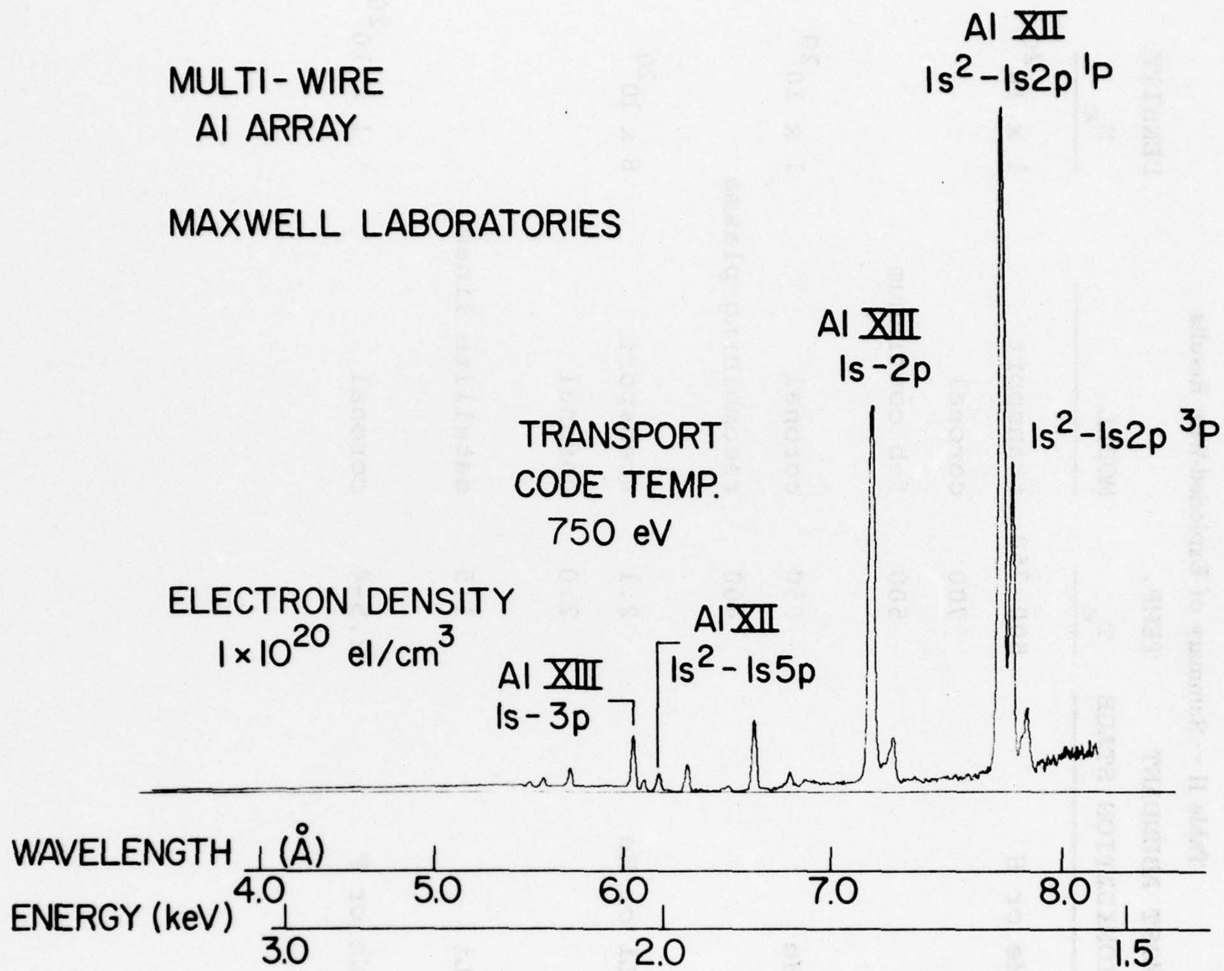

Fig. 1 - X-ray spectral emission of an exploded-Al-wire array (shot BL1) from BLACKJACK 4. Spectral intensities were obtained by processing the digitalized film densities for filter absorption, No-Screen film sensitivity and KAP curved-crystal response.

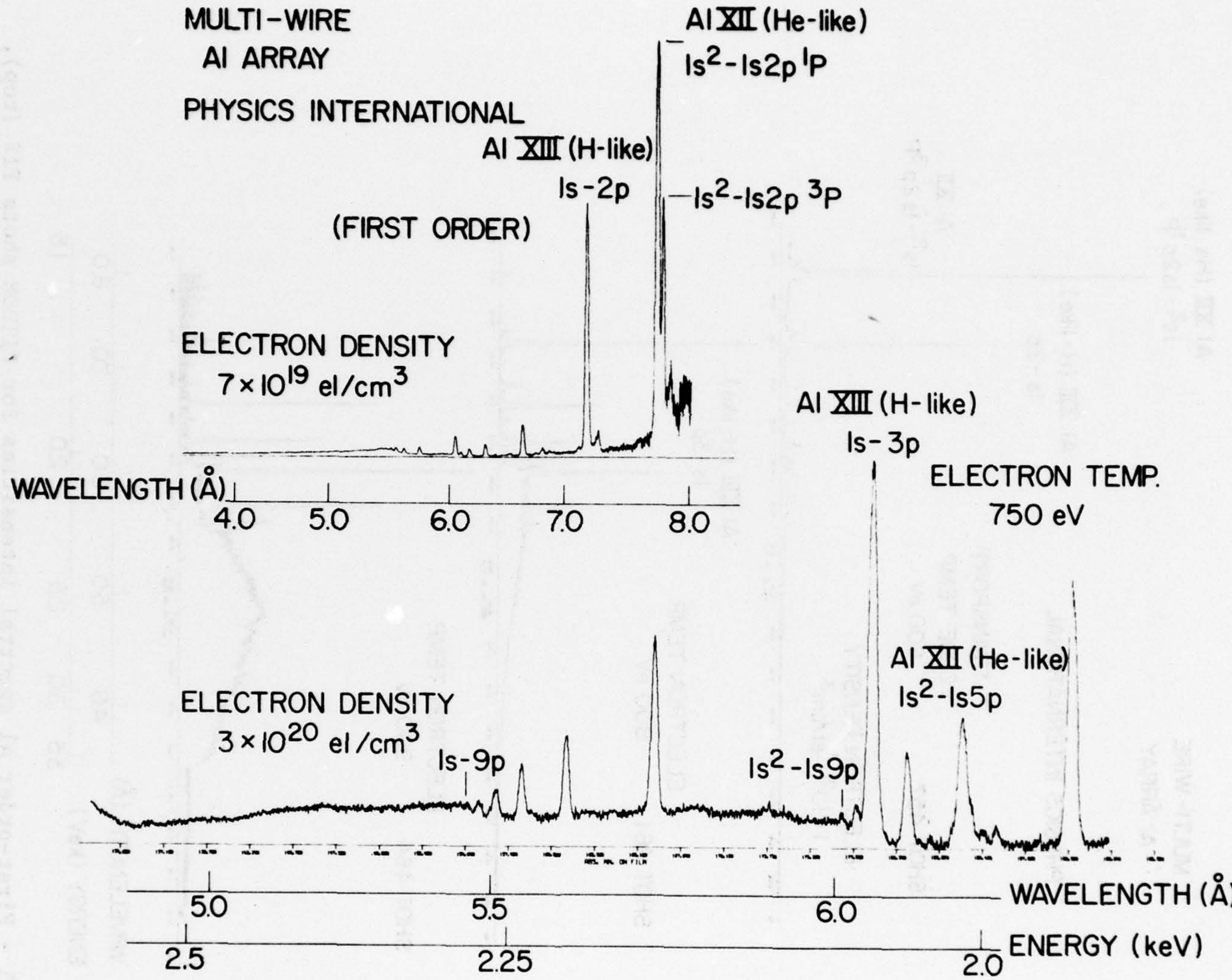

Fig. 2 - Al spectra intensities for PITHON shot PI1. The upper trace shows the entire first order Al spectrum while the bottom trace was diffracted from the (013) plane in KAP.

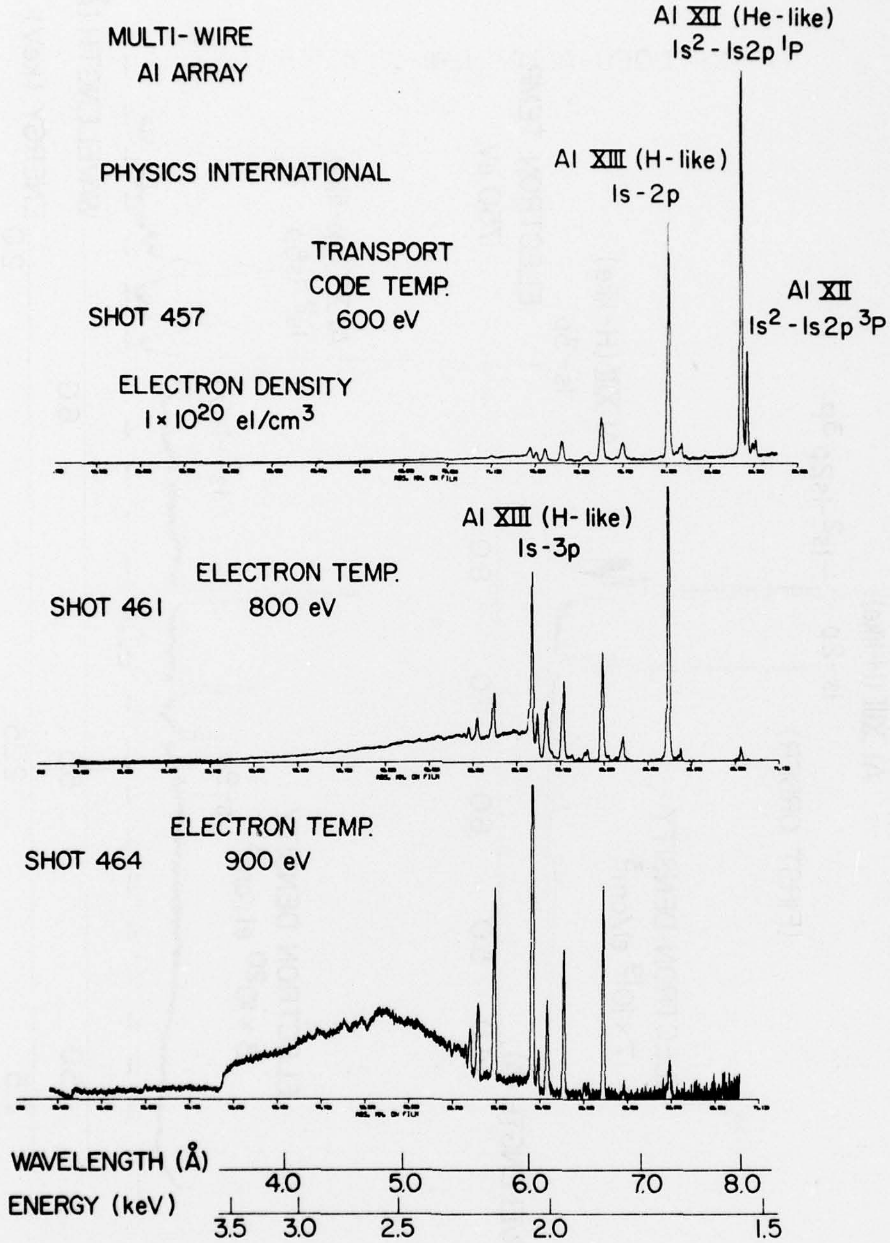

Fig. 3 - First-order Al spectral intensities for PITHON shots PI2 (top), PI3, and PI4 (bottom) acquired from six-wire arrays.

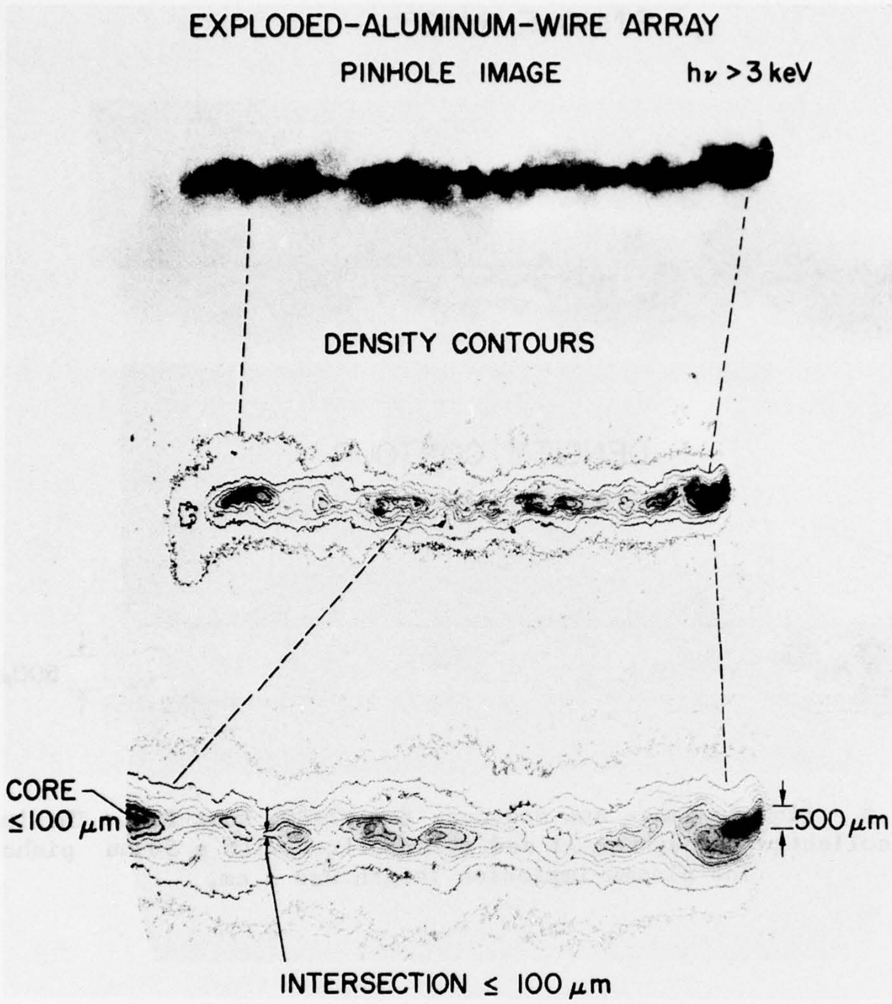

Fig. 4 - Pinhole image and densitometer contours of the image of a 12-wire Al shot PI5 on PITHON. Image was acquired through a 100 μm pinhole. Each contour steps were set at intervals of 0.2 density units. The x-ray image was acquired on the second Fine Grain Positive film. The plasma-implosion length was 3 cm.

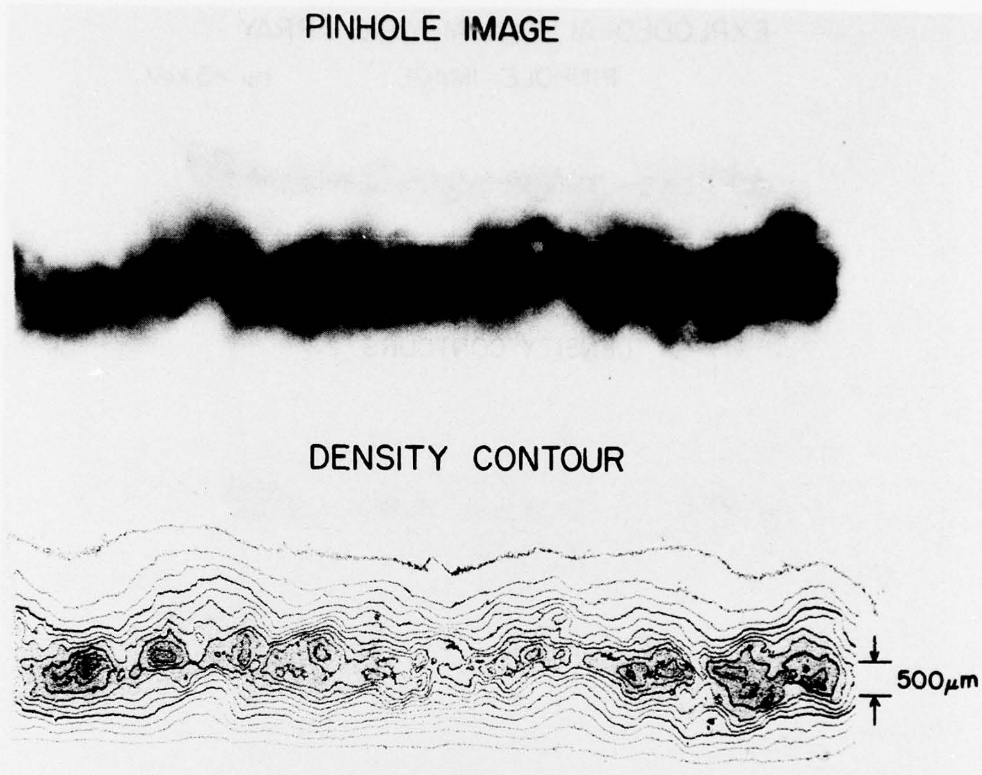

Fig. 5 - Pinhole image and contours for PITHON shot PI2. The image was collected through an Al and mylar filter with a 50 μm pinhole. The plasma-implosion length was 3 cm.

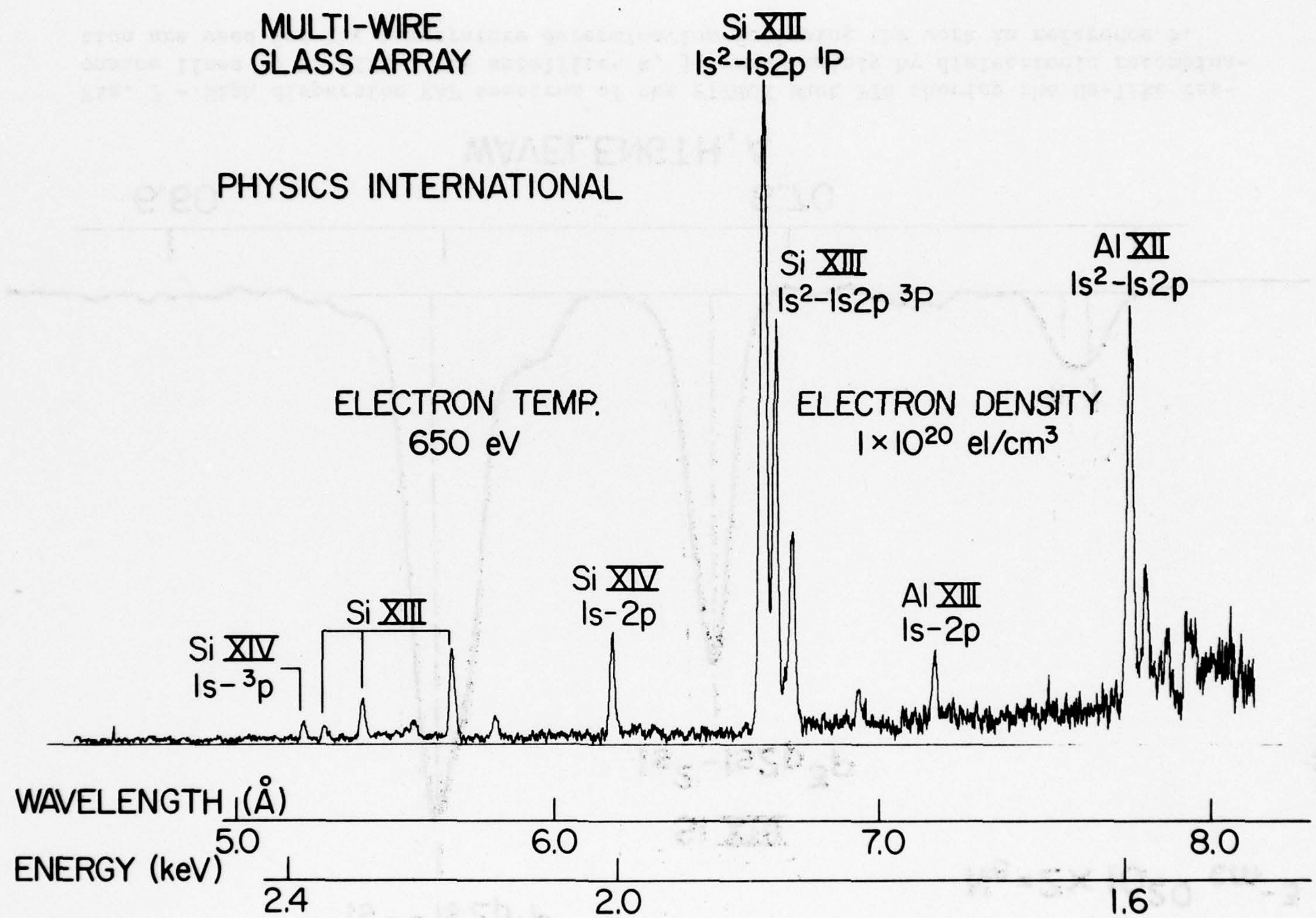

Fig. 6 - X-ray spectral emission from a glass wire array shot PI6 on PITHON.

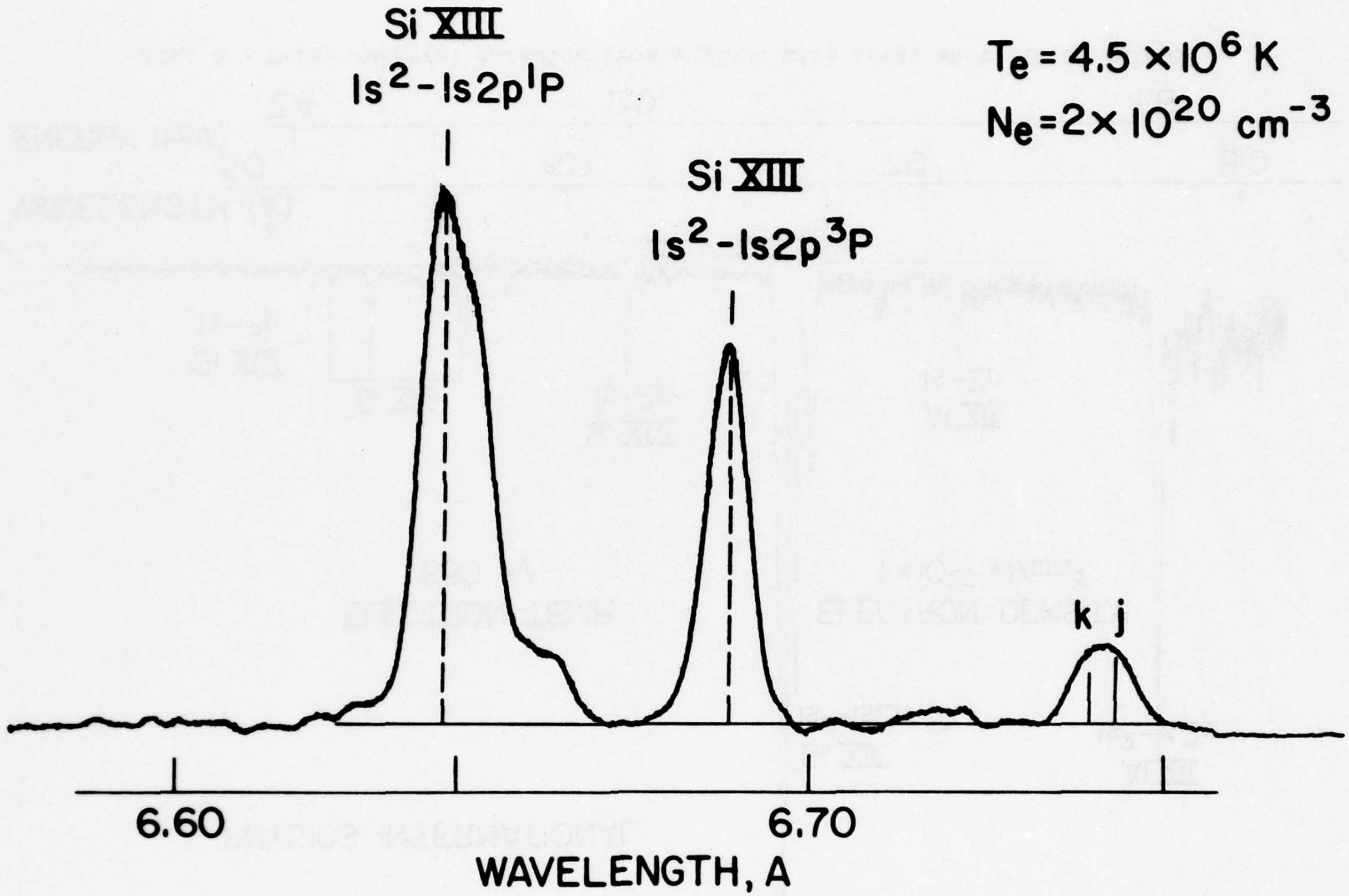

Fig. 7 - High dispersion KAP spectrum of the PITHON shot PI6 showing the He-like resonance lines in Si XIII. The satellites k, j formed mainly by dielectronic recombination are used for the temperature determination following the work in reference 5.

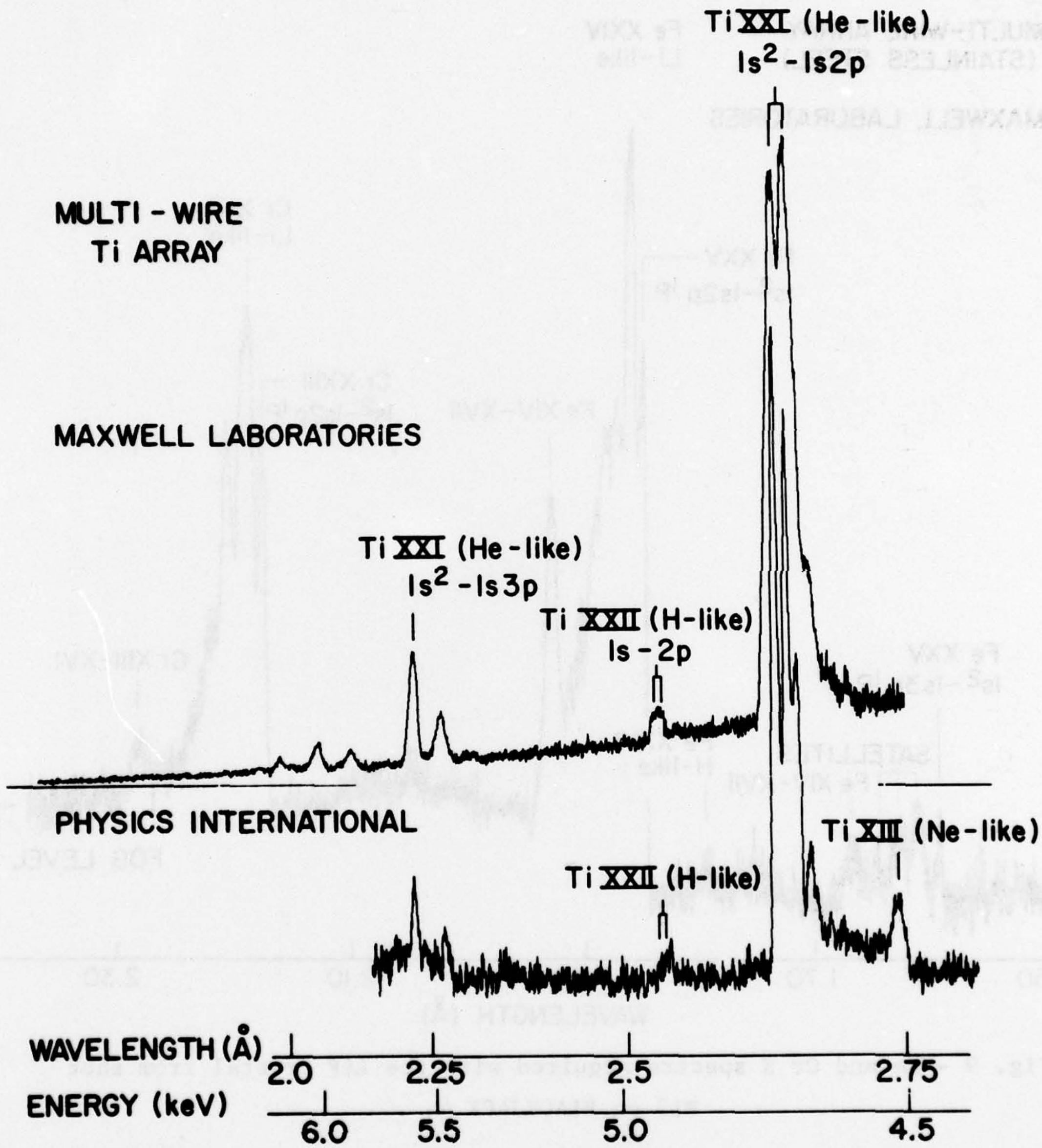

Fig. 8 - Ti spectra from BLACKJACK 4 and PITHON collected with LiF curved-crystal spectrographs.

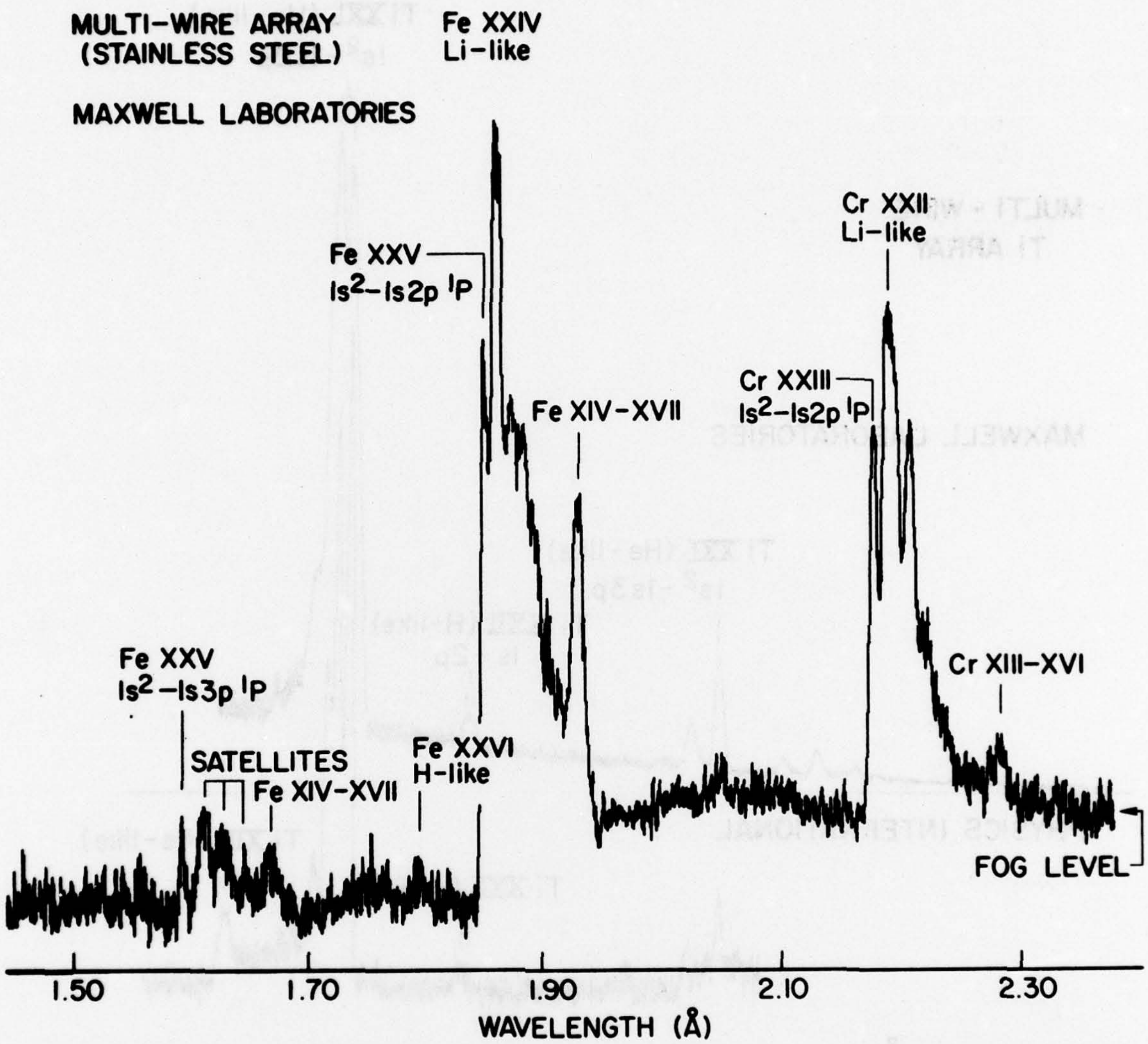

Fig. 9 - Fe and Cr K spectra acquired with the LiF crystal from shot BL3 on BLACKJACK 4.

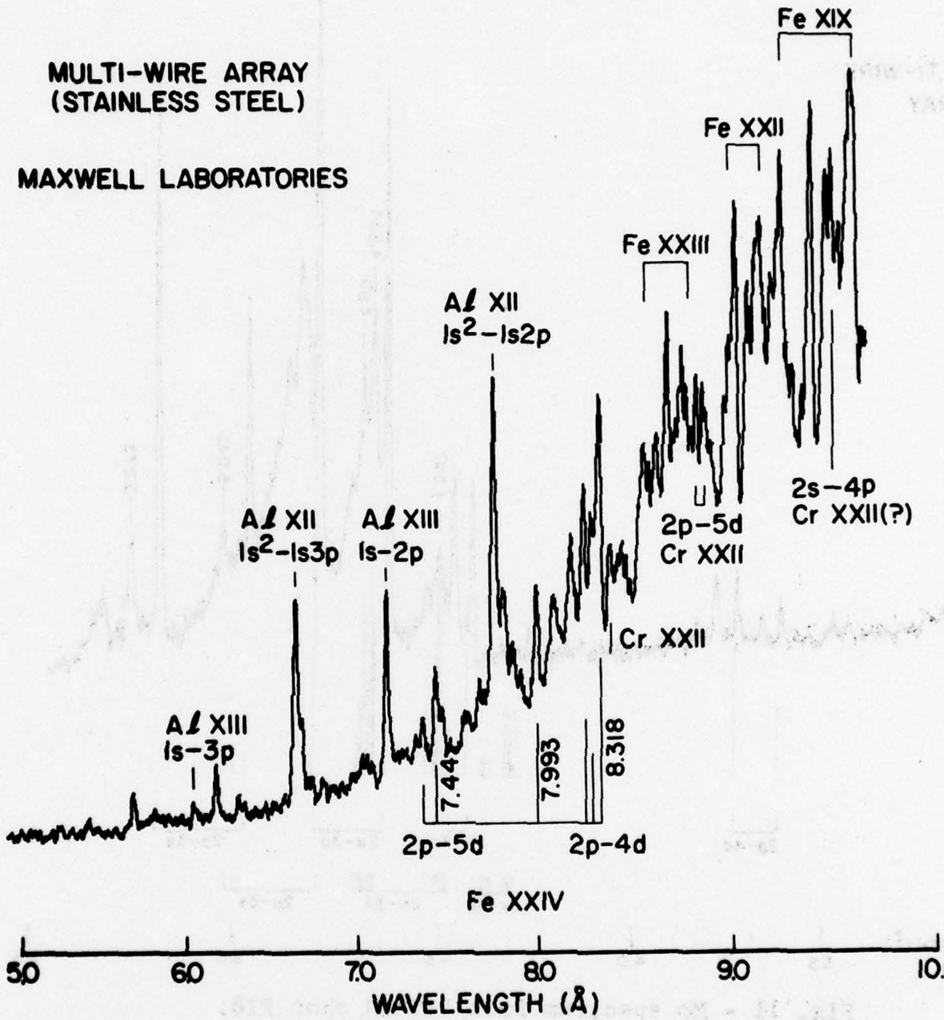

Fig. 10 - Stainless steel spectrum collected with the KAP crystal shot BL3 on BLACKJACK 4.

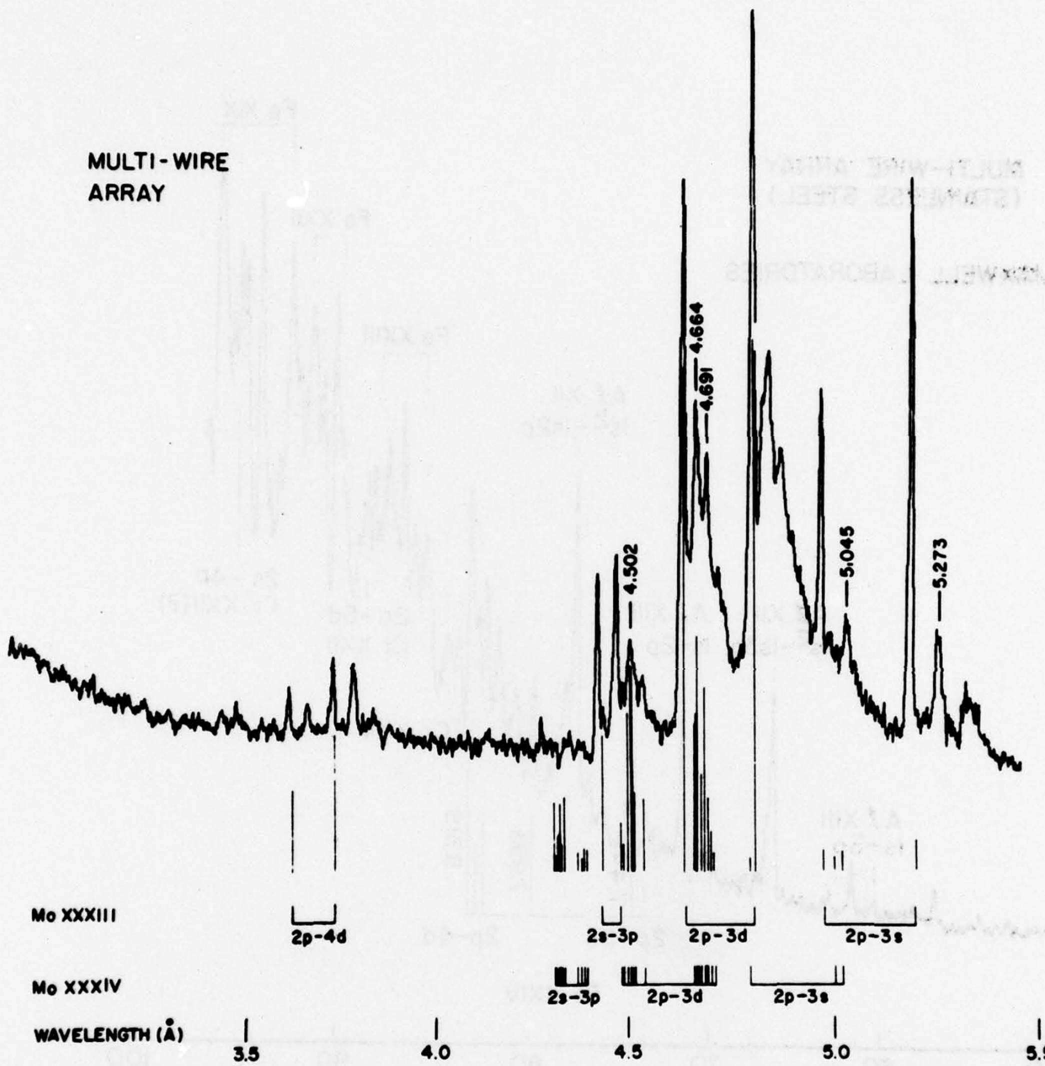

Fig. 11 - Mo spectrum from PITHON shot PI8.

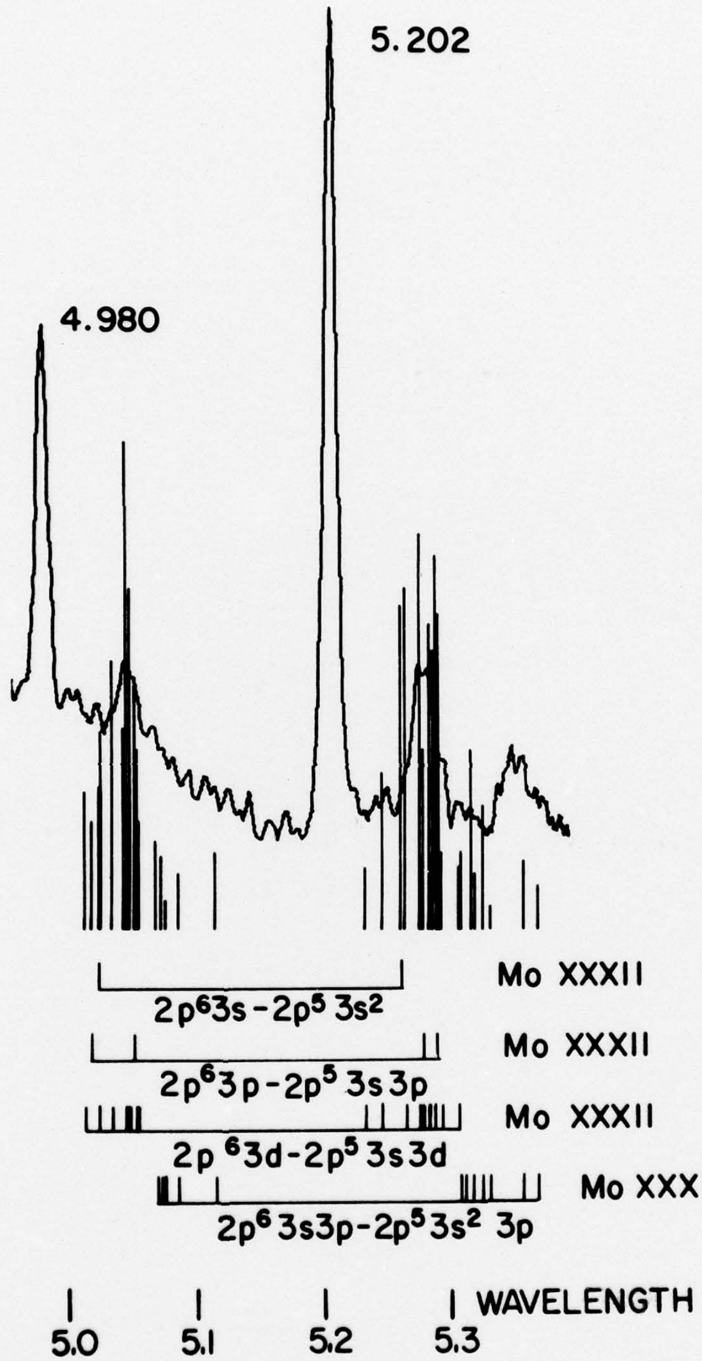

Fig. 12 - Calculated 2 p-3s satellite transitions near 5 Å compared with the multi-wire spectrum.